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SYSTEM COMPRISING AN ELECTRICALLY-ACTIVE OPTICAL COMPONENT WHICH IS CONNECTED TO AN ELECTRONIC BOARD, OPTOELECTRONIC EQUIPMENT AND PRODUCTION METHOD THEREOF

This invention relates to the field of optoelectronics, more precisely to a configuration comprising an active optical component that is electrically connected to an electronic board, an optoelectronic device that is equipped with a box including such a configuration, and a process for their manufacture.

In the known manner, digital optical signals carrying information are generally in the form of a frequency and/or phase modulated optical carrier wave at a frequency that has been increasingly raised, currently roughly 10 GHz.

In optoelectronic devices that transmit these modulated optical signals, an active optical component such as a laser receives on the one hand useful microwave electrical signals for modulation from a driver, and on the other hand is optically coupled to a passive optical system comprising for example guiding means such as an optical fiber, possibly connected to other optical means (collimation lens, optical isolator, etc.).

In receiving optoelectronic devices, an active optical component such as a photodiode receives modulated optical signals from an optical system that is most often passive and at the output delivers useful microwave electrical signals that are generally injected into an electrical preamplifier that is electrically connected to a microwave connector.

The transmitting or receiving active optical component and the elements of the associated optical system are aligned relative to one another during their installation. Then exposed to major temperature variations, these optical components must withstand mechanical stresses to prevent misalignment and must maintain good coupling.

Moreover, these transmitting or receiving optoelectronic devices are housed in increasingly compact boxes for the sake of integration. In these boxes the active optical component is housed and electrically connected via gold wires on a base, ordinarily ceramic, and this assembly is arranged and electrically connected via gold wires on a suitable support of the electronic board type that ensures interconnections.

Patent application EP 1 154 298 suggests a configuration that comprises a photodiode, with a photosensitive surface located on one of the faces, that is attached directly to one end of an optical fiber by means of an optically transparent adhesive. The adhesive joint thus constitutes the only mechanical attachment of the photodiode such that this system does not

require the use of a base; thus, this reduces the number of parts used. Such a configuration is designed to reduce misalignment of the optical fiber and the photodiode relative to one another. Gold wires ensure the interconnections between the photodiode, the electronic board and an electrical preamplifier.

The quality of the interconnections is critical for microwave applications and the use of interconnection wires is not desirable. In fact, it is difficult to adapt their impedance in this range of increased frequencies because this entails radically minimizing their lengths.

Moreover, forming contacts by soldering each of these interconnecting wires is tricky; such an operation is manual, not very reliable and does not allow high production volumes, so therefore it is a costly operation.

Document US 6 164 838 A proposes a configuration that comprises, in the eighth embodiment shown in Figure 17, a configuration comprising a photodiode module that is electrically connected to an electronic board via three lugs and coupled to one end of an embeddable optical fiber by a ferrule.

The electronic board is a flexible circuit called a multilayer FPC selected in order to reduce the stresses arising from the attachment or detachment of the configuration from its environment, for example a computer. Consequently, it is possible to manage the stresses.

Nevertheless the quality of the interconnections remains inadequate. In addition, the suggested configuration is not only inefficient at high speed, but it is complicated to implement, difficult to integrate, and costly.

The object of this invention is to provide a simple, compact and inexpensive configuration, comprising an active optical component that is electrically connected to an electronic board and designed to be optically aligned with an optical system. This configuration must be adapted to high speeds and must be free of mechanical stresses.

This invention is likewise intended to provide a simple, compact and inexpensive optoelectronic device that is equipped with a box comprising an active optical component that is electrically connected to an electronic board and optically aligned with an optical system. This unit must be efficient at high speeds and must not be highly susceptible to thermal fluctuations, in order to maintain the optical alignment.

Finally, this invention is intended to provide a process for manufacture of this configuration and of this device, which is simple, fast, inexpensive, allowing precision assembly, with a capacity for automation, in other words, easily compatible with industrial requirements.

To do this, this invention proposes a configuration comprising an active optical component that is electrically connected to a flexible electronic board, the active optical component being designed to be aligned with an optical system, characterized in that the electronic board is a flexible circuit with a high density of interconnections, called a HDI flexible circuit, with an upper longitudinal surface that comprises a metallic brazing sector in contact with a microwave transmission path of the HDI flexible circuit, and [also characterized] in that the active optical component on one of its surfaces, i.e. the contact surface, comprises a metallic contact sector that coincides directly with the metallic brazing sector by turning said active optical component over onto the HDI flexible circuit.

A flexible circuit is defined as a deformable electronic board, and thus able to relieve mechanical stresses and even to miniaturize the configuration (by bends, etc.). These advantages are not afforded by the rigid or semi-rigid electronic boards ordinarily used in optoelectronic devices.

Moreover, a HDI circuit is defined as an electronic board with an interconnection circuit in thin layers that may be engraved. By means of this technology, the insulating zones between the transmission path or paths of the useful electrical signals and the ground zones can be reduced and controlled for microwave applications in the same way as the widths of the paths. These paths are thus compatible with microwave frequencies and easily allow adaptation of impedances.

HDI flexible circuits (from the English, High Density Interconnection Flex Circuit) are already available on the market and are used in areas such as mobile telephony or medicine. In these fields the electronic components are assembled primarily by bonding.

The HDI flexible circuit as claimed in the invention has a design adapted to microwave frequencies and supports an inverted active optical component ('flip-chip' transfer) and is assembled by brazing.

This direct support by brazing of the 'flip-chip' type affords several advantages both at the level of enhanced performance and also at the level of its cost. This avoids the use of a base and interconnection wires and allows exact positioning of the active optical component. This can also facilitate its alignment with the optical system.

In a support made directly by bonding, the adhesive can spread and cause short circuits. In a support made directly by thermal compression, the active optical element can break under the action of the applied pressure or can be degraded by high temperatures. All these disadvantages are avoided by the approach as claimed in the invention.

The HDI flexible circuit as claimed in the invention thus comprising a metallic brazing sector is thus able to withstand the conditions of brazing metal deposition as well as the conditions of transfer of the active optical component to the melting temperature of the metal for a few seconds.

The brazing metal can be for example a gold-tin alloy that has a melting point between 250°C and 300°C or a lead-tin alloy. The contact metal, as for itself, can be gold.

Advantageously, the metallic brazing sector can comprise a network of metallic brazing contact studs with a diameter of roughly 30 μm.

Contact studs of such a small diameter cannot be implemented with adhesive and these reduced sizes allow limitation of parasitic capacitances.

In one preferred embodiment, the upper longitudinal surface of the HDI flexible circuit comprises a zone of electrical insulation arranged in an essentially annular configuration around one of the ends of the microwave transmission path and extending through a flared zone of electrical insulation. In this embodiment, one of the metallic brazing contact studs, i.e. the central contact stud, is located on this end of the path and the other metallic brazing contact studs are distributed essentially in a semi-circle or semi-circles on a ground conductive zone, in the vicinity of the side of said annular electrical insulation zone.

These particular forms of the electrical insulation zones with ordinarily air gaps make it possible to move the microwave signal away from ground to the level of the active optical component such as a photodiode to optimize its performance (design "microstrip").

In this latter embodiment, the flared electrical insulation zone can end in a narrowed electrical insulation zone.

This design of the coplanar type is intended to move most of the useful microwave signals that much closer to the input of the active electronic component mounted on the HDI flexible circuit.

Preferably, the active optical component can be chosen from among a photodiode that is able to receive modulated optical signals by the longitudinal surface, i.e. the receiving surface, which is parallel to the contact surface, and a laser that is able to supply modulated optical signals by the longitudinal surface, i.e. the transmission surface, which is parallel to the contact surface.

In one advantageous embodiment, the upper longitudinal surface of the HDI flexible circuit comprises another metallic brazing sector, said other sector being in contact with one of the ends of the microwave transmission path and with another microwave transmission

path of the HDI flexible circuit. In this embodiment, the configuration likewise comprises an active electronic component that has, on one of its surfaces, i.e. the contact surface, a metallic contact sector that coincides directly with said other metallic brazing sector by turning the active electronic component over onto the HDI flexible circuit.

The active electronic component can be for example a preamplifier or a driver.

This invention also proposes an optoelectronic device equipped with a box, which comprises the configuration such as described above as well as an optical system aligned with the active optical component, the configuration and the optical system being kept in the box.

When the active optical component is chosen from among said photodiode and said laser, the HDI flexible circuit is bent and the upper longitudinal surface comprises a first part facing the bottom of the box extended by a second part containing said brazing sector facing one of the lateral transverse surfaces of the box.

This particular assembly makes it possible to receive, at the input of the box, modulated optical signals propagating essentially parallel to the bottom of the box, and to transmit at the output microwave electrical signals propagating essentially in the same plane.

The receiving surface of the active optical component can be attached by an optically transparent adhesive to one end of an optical fiber integral with said lateral transverse surface of the box, in such a way as to maintain good optical alignment.

This invention finally proposes a process for manufacture of a configuration such as described above, <u>characterized in that</u> it comprises the following stages:

- the stage of formation of the metallic brazing sector of the HDI flexible circuit by physical vapor phase deposition,
- the stage of formation of the metallic contact sector of the active optical component,
- the stage of installation of the active optical component on the HDI flexible circuit by turning it over and brazing.

Physical vapor phase deposition is ordinarily of the cathodic sputtering or vacuum evaporation type.

The stage of assembly as claimed in the invention is fast, can be automated, and leads to exact positioning of the active optical component.

The manufacturing process can comprise the following stages:

- the stage of formation of another metallic brazing sector of the HDI flexible circuit by physical vapor phase deposition,
- the stage of formation of the metallic contact sector of the active electronic

component,

– the stage of installation of the active electronic component on the HDI flexible circuit by turning it over and brazing.

Finally, this invention proposes a process for manufacture of an optoelectronic device such as described above, characterized in that it comprises the stages of manufacture of a configuration as have already been described, and [also characterized] in that it comprises a stage of supporting the configuration and the optical system in said box, including the bending of the HDI flexible circuit.

When the optoelectronic device is designed to include an optical fiber attached to the active optical component, the stage of supporting the configuration and the optical fiber in the box includes the following:

– bonding the optical fiber in one of the lateral transverse surfaces and bonding the active electronic component in the bottom of the box,

– soldering the end of the HDI flexible circuit to one interconnection located at the level of the other of the lateral transverse surfaces of the box.

The specifics and advantages of the invention will become apparent from reading the following the description that is given by way of an illustrative and non-restrictive example, with reference to the attached figures.

- Figure 1 schematically shows a top view of a HDI flexible circuit as claimed in the invention,
- Figure 2 schematically shows a bottom view of the HDI flexible circuit from Figure 1,
- Figure 3 schematically shows the stage of assembly by turning an active optical component over onto the HDI flexible circuit from Figure 1,
- Figure 4 schematically shows a side and lengthwise view of an optoelectronic module comprising the HDI flexible circuit, the active optical component from Figure 3 and an active electronic component, all of which are assembled by turning over and brazing according to one preferred embodiment of the invention,
- Figure 5 schematically shows a side view and a longitudinal section of an optoelectronic device equipped with a box incorporating the module from Figure 4,
- Figure 6 schematically shows a top view of the optoelectronic device from

Figure 5, without the cover of the box.

Figure 1 schematically shows a top view of a HDI flexible circuit 10 corresponding to an electronic board as claimed in the invention.

The HDI flexible circuit 10 comprises one upper longitudinal surface 10a designed to accommodate an active optical component (as shown by the rectangle at point X), for example a receiving component such as a photodiode, and an active electronic component (as shown by the rectangle at point X'), for example a preamplifier.

The HDI flexible circuit 10 is composed of an insulating substrate 1 of polyimide, for example with a thickness of roughly 15 μm. This substrate 1 is covered by a metallic multiple layer 2 composed in the following order of a copper layer (not visible) with a thickness between 1 and 20 μm and for example equal to 7 μm, of a nickel layer (not shown) with a thickness of roughly 1.5 μm, and with a layer of gold with a thickness between 0.3 and 1.5 μm.

These thin metallic layers are deposited using classical deposition techniques (by cathodic sputtering or by evaporation). By means of a system of masking and chemical engraving, the multiple layer 2 will form grounds and microwave transmission paths as well as the electrical feed paths of the preamplifier. If necessary, the multiple layer can also be used to form capacitances, resistances and inductances.

More precisely, the upper longitudinal surface 10a comprises a microwave transmission path, called the HF input path 3 for propagation of useful microwave signals at 10 GHz between the photodiode and the preamplifier. The width of the HF input path 3 is reduced in the vicinity of the photodiode, then widens.

The HF input path 3 is separated from the ground, i.e. the input ground 4, by an electrical insulation zone 5 in the form of an empty space above the polyimide substrate 1, fundamentally in three parts 51, 52, 53. The first part 51, which is located in the vicinity of the input end of the HF input path 4 (photodiode side), is essentially in the shape of a ring and ends in the second flared part 52, which has been formed by two fins 52a, 52b on either side of the HF input path 3. The fins end in a third part 53, which has been formed by two rectangles 53a, 53b.

For HF performance optimized to 10 GHz, the ring 51 and the fins 52a, 52b have a width of roughly 100 μm and 200 μm respectively, and the rectangles 53a, 53b have a width less than or equal to 50 μm and preferably less than or equal to 20 μm. Likewise, the HF input path 3 has a width of roughly 300 μm. Figure 1, schematic, is not to scale.

At the level of the zone X, which is intended for mounting the photodiode, the upper longitudinal surface 10a comprises a metallic brazing sector in the form of a network 6 of brazing contact studs with a circular base (of the bump type) preferably of a gold-tin alloy and preferably with a diameter of roughly 30 μm. The central contact stud 61 is located on the end of the HF input path 3 and the other brazing contact studs 62 are distributed essentially in two semi-circles on the input ground 4 in the vicinity of the side of the annular space 51.

At the level of the zone X', which is intended for mounting the preamplifier, the upper longitudinal surface 10a comprises another metallic brazing sector 7 in the form of a network of brazing contact studs with a square base, preferably of a gold-tin alloy.

Three input contact studs 71 to 73 are located above the two output ends of the HF input path 3 and of the input ground 4.

For example, six contact studs 7a to 7f are located respectively on the input ends of six low frequency electrical supply paths, i.e. BF paths 8a to 8f, which extend laterally. Three output contact studs 71' to 73' are located on the input ends of the output microwave transmission path 3' of the useful amplified HF signals and of two ground paths 4', 4" on either side of this HF output path 3'. The output ends of the six BF paths 8a to 8f are tabs to be connected, which do not rest on the substrate 1.

The number of brazing contact studs for electrical feed and their distributions depend on the active electronic component to be installed as well as the number of BF paths. Moreover, decoupling capacitances can be implemented.

Likewise, the ends of the ground and HF output paths 4', 4", 3' are tabs to be connected 9 without resting on the substrate 1.

The brazing sectors 6, 7 have been formed by physical vapor phase deposition on gold and by masking.

Figure 2 schematically shows a bottom view of the HDI flexible circuit 10, illustrating the lower longitudinal face 10b of polyimide I, the ends in the form of connection tabs 9 of the HF output path 3' and of the ground paths 4', 4" and the output ends of the BF paths 8a to 8f.

Figure 3 schematically shows the stage of assembly by turning the photodiode 20 over onto the upper longitudinal surface 10a of the HDI flexible circuit 10.

The longitudinal contact surface 20a of the photodiode 20 is provided with a metallic contact sector 21 in the form of a network of gold contacts of the cylindrical type, comprising a central contact 211 and contacts 212 in two semi-circles to coincide with the network of

brazing contact studs 6 at the time of turn-over (shown by the arrow F). Then brazing is done to secure the photodiode 20.

The photodiode 20 is of the surface illumination type: it receives modulated optical signals by the receiving longitudinal surface 20b, which is parallel to the contact surface 20a.

Figure 4 schematically shows a side and lengthwise view of the optoelectronic module 200 comprising a configuration 100, which includes a HDI flexible circuit 10, a photodiode 20 and a preamplifier 50, all of which are assembled by turning over and brazing according to one preferred embodiment of the invention.

The preamplifier 50 on the longitudinal contact surface 50a comprises a metallic contact sector (not shown) in the form of a network of square gold contacts arranged on the brazing contact studs of the support 73, 7d, 7e, 7f, 73', themselves on the gold layer of the metallic multiple layer 2.

The receiving surface 20b of the photodiode 20 parallel to the contact surface 20a is attached to one end of an optical fiber 30 by an optically transparent adhesive 40. The optical fiber 30 and the photodiode 20 are aligned to one another by optimum coupling.

Figure 5 schematically shows a side view and a longitudinal section of an optoelectronic device 300 for receiving modulated optical signals, provided with a box 60, which incorporates the module 200.

The box 60 is composed of a bottom of the box 61 and a cover 64 and of two lateral transverse input and output surfaces 62, 63. The lateral input surface 62 receives the optical fiber 30 held by an adhesive 31, or, in one version, by brazing. The lateral output surface 63 receives isolating inserts 81, 82 as well as a gold interconnection layer 83 in contact by soldering with the tab 9 and in contact with the output pins 84.

After installing and supporting the module 200, the HDI flexible circuit 10 has a bend 111 such that the upper longitudinal surface 10a comprises a first part relative to the active electronic component with respect to the bottom of the box 61, extended by a second part relative to the active optical component with respect to the lateral transverse input surface 62. Moreover, on the side of the lateral transverse output surface 63, the HDI flexible circuit 10 for example has a second bend 112, which is designed to be adapted to the height of the inserts 81, 82.

When the box 60 and the optical fiber 30 expand or contract due to temperature variations, the HDI flexible circuit will be consequently deformed (as shown by the arrow J); this prevents the fiber from breaking.

The longitudinal surface 50b of the preamplifier 50, which is parallel to the contact surface 50a is attached to the bottom of the box 61 by means of an adhesive 51 in order to reduce heat dissipation.

Figure 6 shows a top view, without the cover of the box 60, of the receiving optoelectronic device 300, emphasizing the connections of the output ends of the BF paths 8a to 8f on the inserts 85, 86 at the level of the transverse longitudinal surfaces 65, 66.

The receiving optoelectronic device 300 without interconnection wire or base is adapted to microwave frequencies, is inexpensive, easy to produce, and compact. This device is not subject to increased mechanical stresses.

In a first version of this preferred embodiment, the photodiode can be replaced by a laser, for example for emission through the surface, and the preamplifier can be replaced by a driver in order to make a transmitting optoelectronic device. In this case, classic means of controlling the laser temperature can be added.

In a second version of this preferred embodiment, the HDI flexible circuit as claimed in the invention can comprise a stack composed of several metallic multiple layers such as the multiple layer 2, which are separated by several insulating substrates of polyimide for example with a thickness of 7 μm such as the substrate 1, these different metallic multiple layers being able to be interconnected via metal coated holes formed in one or the other of the insulating substrates.

Of course, the invention is not limited to the embodiment that was just described.

The use of an active electronic component is not always necessary.

The optical system aligned with the photodiode or any other active optical component can be composed of means other than the optical fiber (electro-opto-mechanical microsystem, lenses, isolators, variable optical attenuator...).

The invention also makes it possible to design devices operating at frequencies exceeding 10 GHz, for example roughly 40 GHz.

Finally, any means can be replaced by an equivalent means without departing from the framework of the invention.